

Resonances in High-Intensity Linacs (& Rings)

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Snowmass, July 11, 2001

1. Non-equipartitioned Beams

2. Resonance Charts

3. Halo & Loss

Acknowledgment:

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F. Gerigk, CERN,

R..A. Jameson, LANL

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Types of Resonant Motion

Emittance growth and halo result mainly from resonance

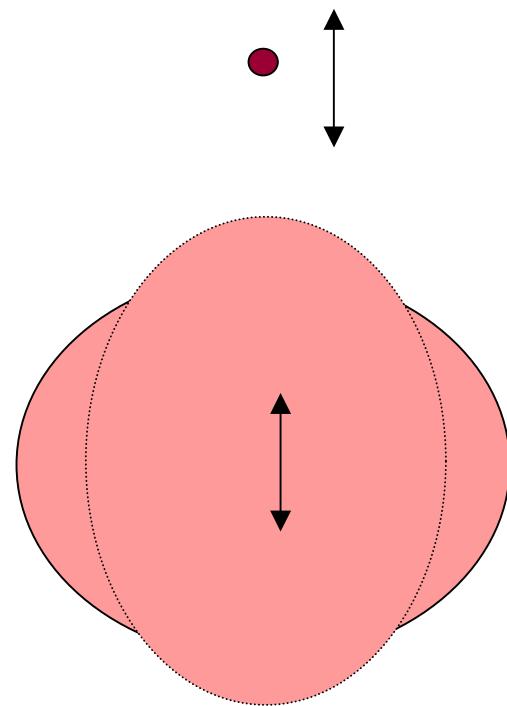
other negligible sources (% or less):

- intrabeam scattering
- conversion of nonlinear field energy
- filamentation in nonlinear rf potential

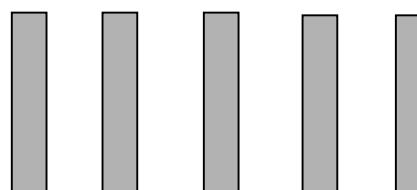
Thermodynamics has no place in space charge dominated beams

3 kinds:

Single particle resonance with core -> halo



Coherent core resonance with itself -> rms growth



Coherent core resonance with periodic structure
Avoid: $\sigma_0 > 90^\circ$

Most studies are on isotropic beams

Isotropic cores are stable (non-KV)

Numerous halo studies (2:1 halo extent to 4-5 σ)

Anisotropy (different focusing and/or emittances)
brings new features:

Core: non-equipartition issue – *energy transfer by collective resonance*

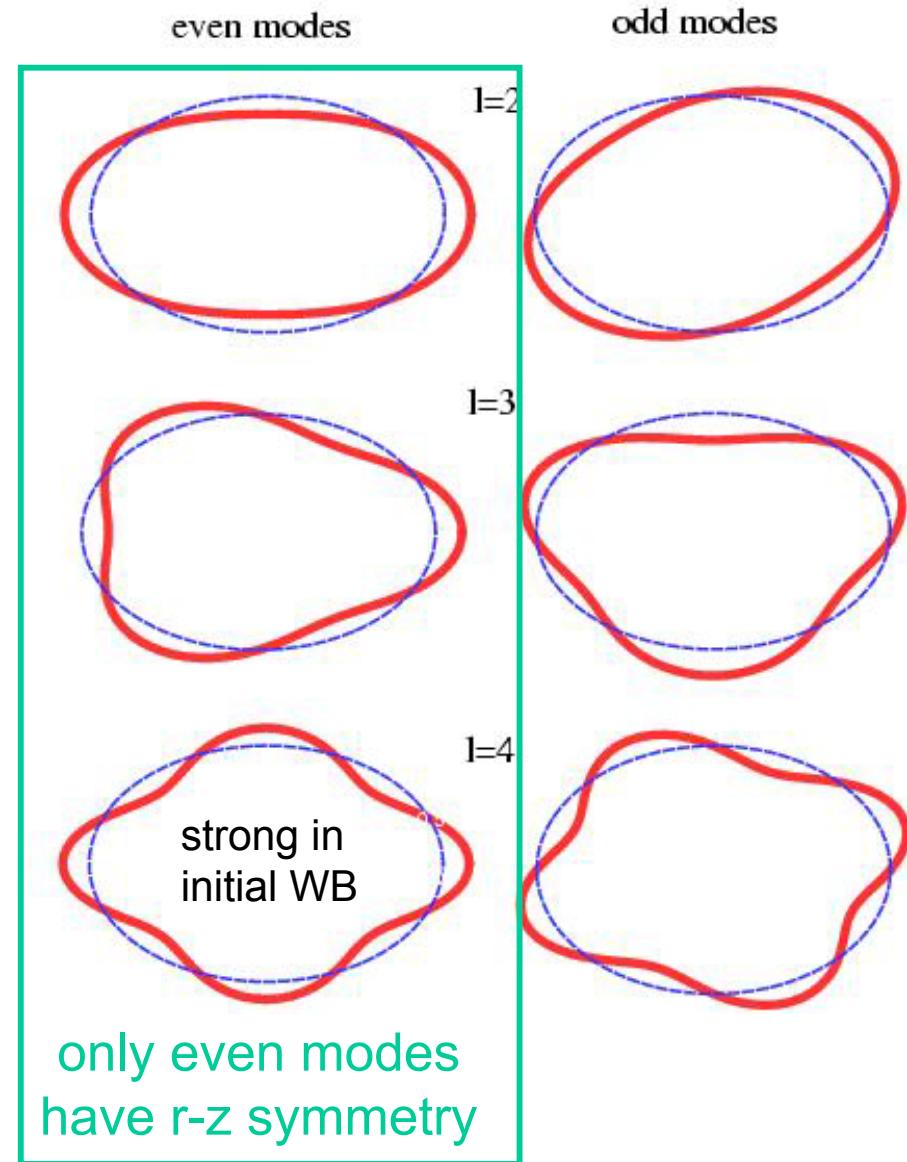
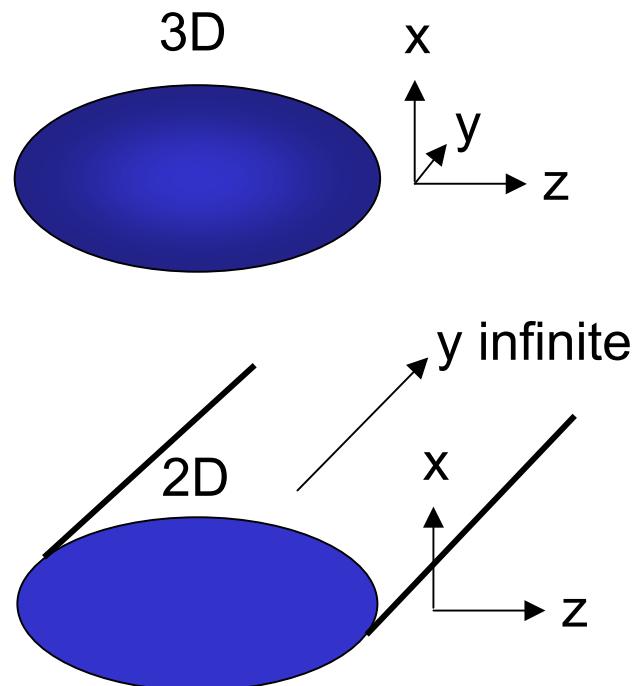
Halo: halo size and density depend on tune ratios

Qiang, I.H., Ryne (PAC01) – 2:1 halo extent to *infinity*

We have explored this systematically in 2D/3D and
continuous focusing to enlarge physics basis for
SNS linac studies

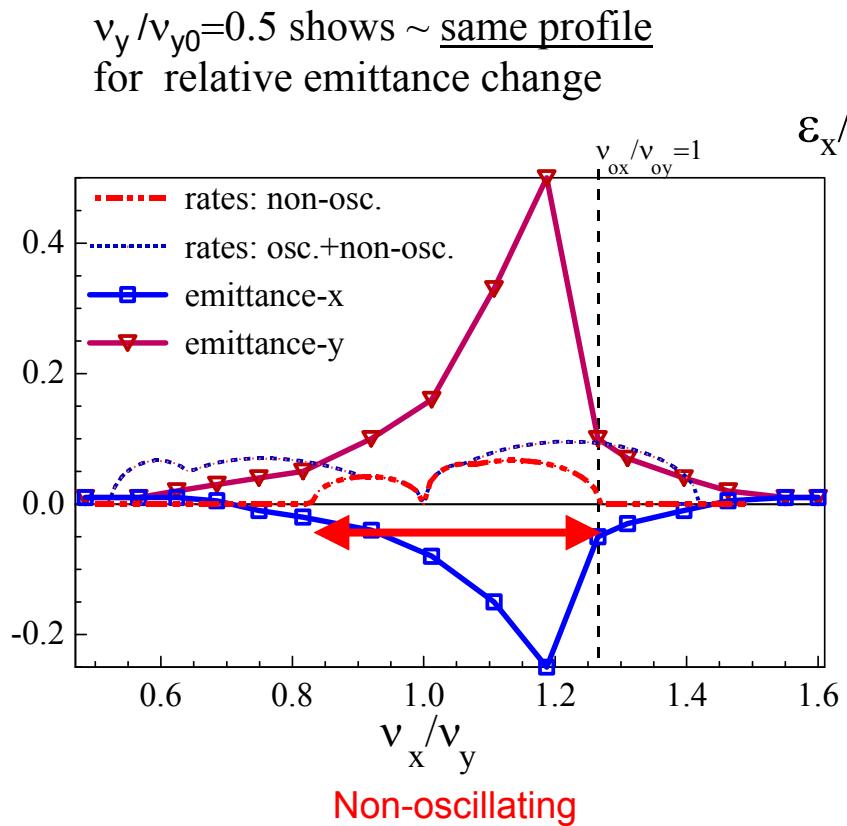
Core eigenmodes are multipole oscillations in density

analytical KV-theory I.H., Phys.Rev.E, 1998



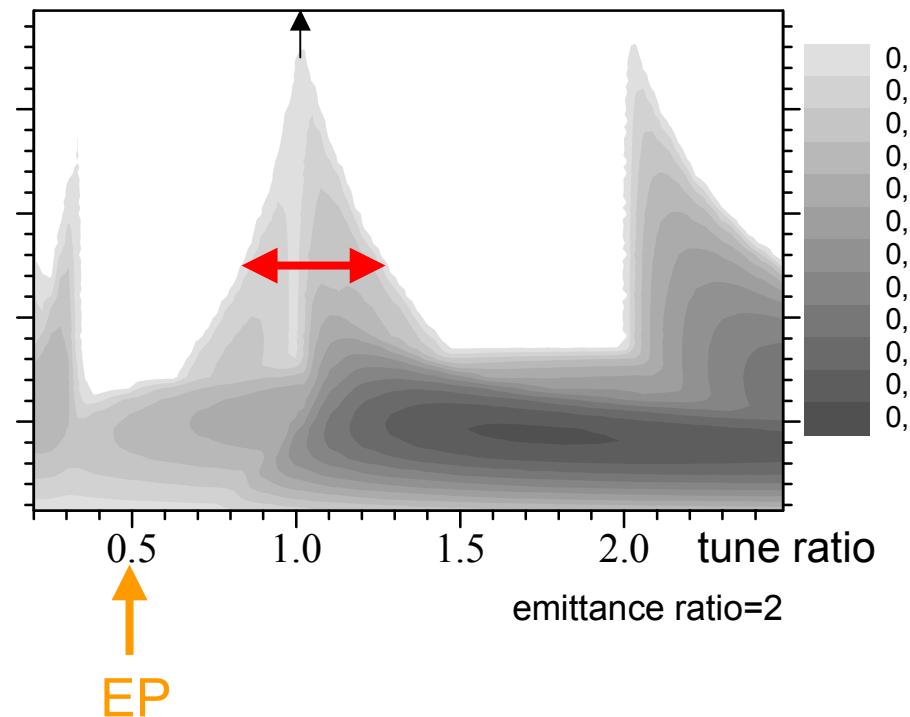
Simulation is strongly supporting the thesis:
 Stopbands of unstable non-oscillating (only!) KV modes
 characterize behavior of „real“ beams
 -> basis for our *resonance charts*

Likely reason: oscillating KV-instabilities are Landau-damped in real beams



Charts including rates based
on analytical KV-theory

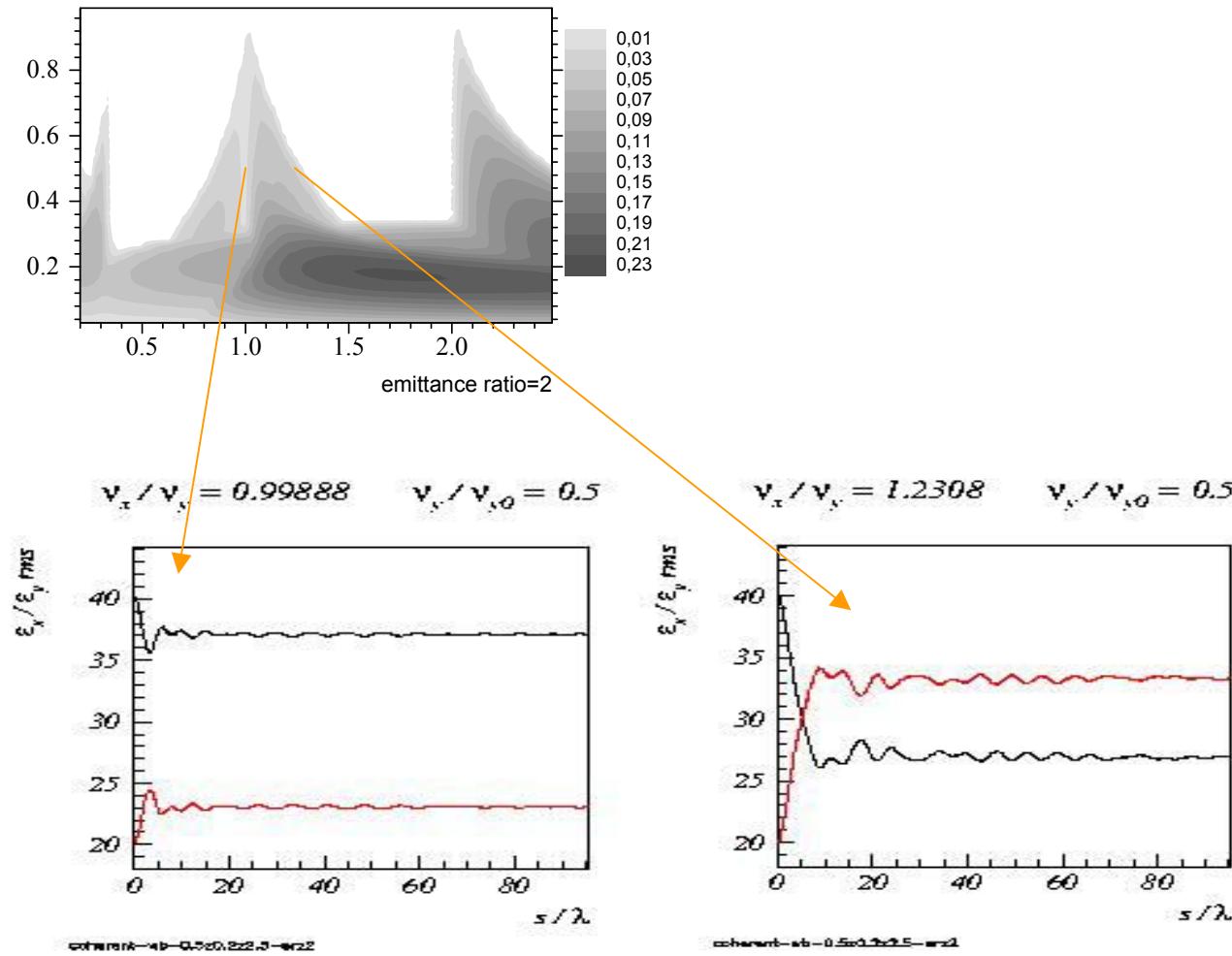
I.H., Phys.Rev.E, 1998



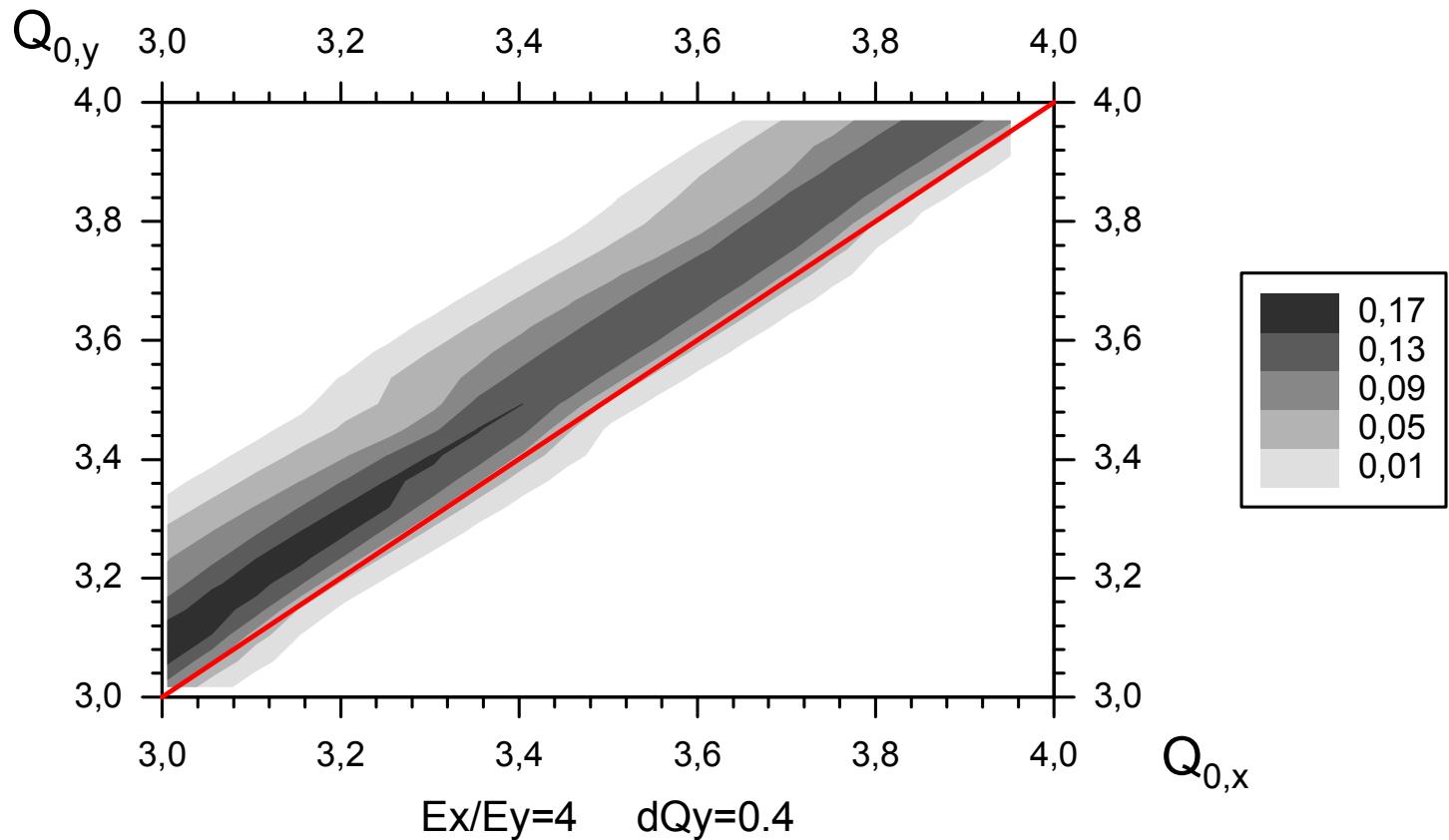
see I.H. and O. Boine-Frankenheim, PRL 87 (June 2001)

Examples of emittance exchange in 2D

Approach to equipartition depends on where on stopband



Rings: stopband at $k_x/k_y \sim 1$ known as “Montague-resonance”: $2Q_{x0} - 2Q_{y0} \sim 1$



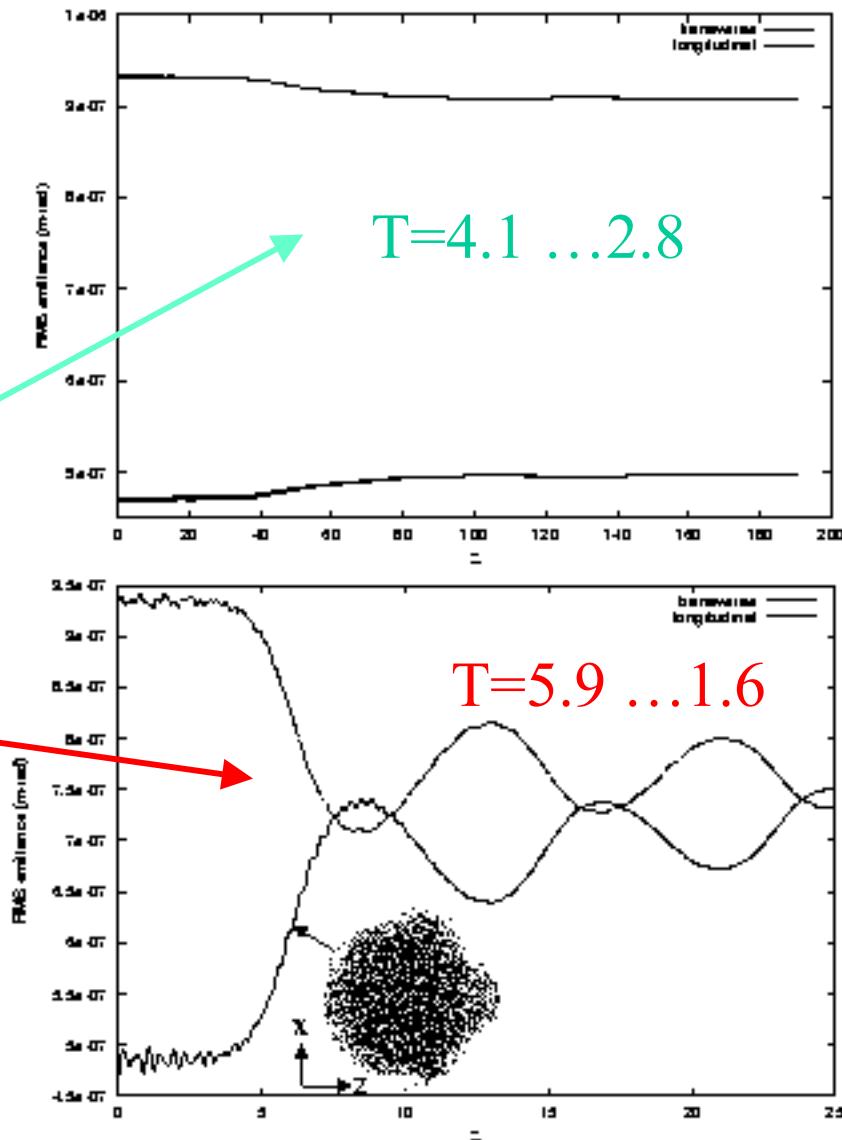
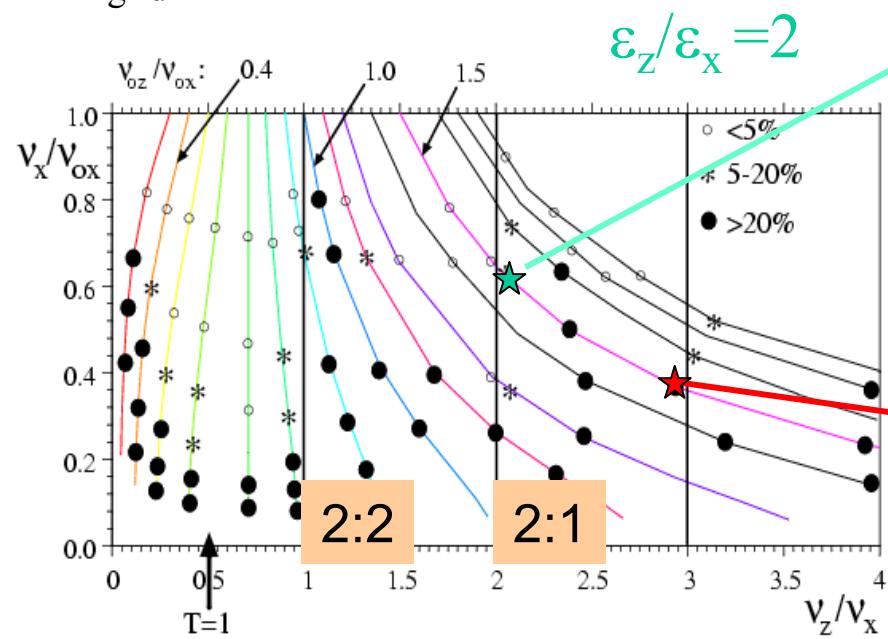
- Montagues analysis was *incoherent* – fixed space charge potential – coherent more adequate
- ~ explains measurement reported at KEK booster (Sakai, Machida, PAC01)

Applied to Linac: fully 3D simulation

- using IMPACT code (R. Ryne, J. Qiang, LANL) in constant focusing

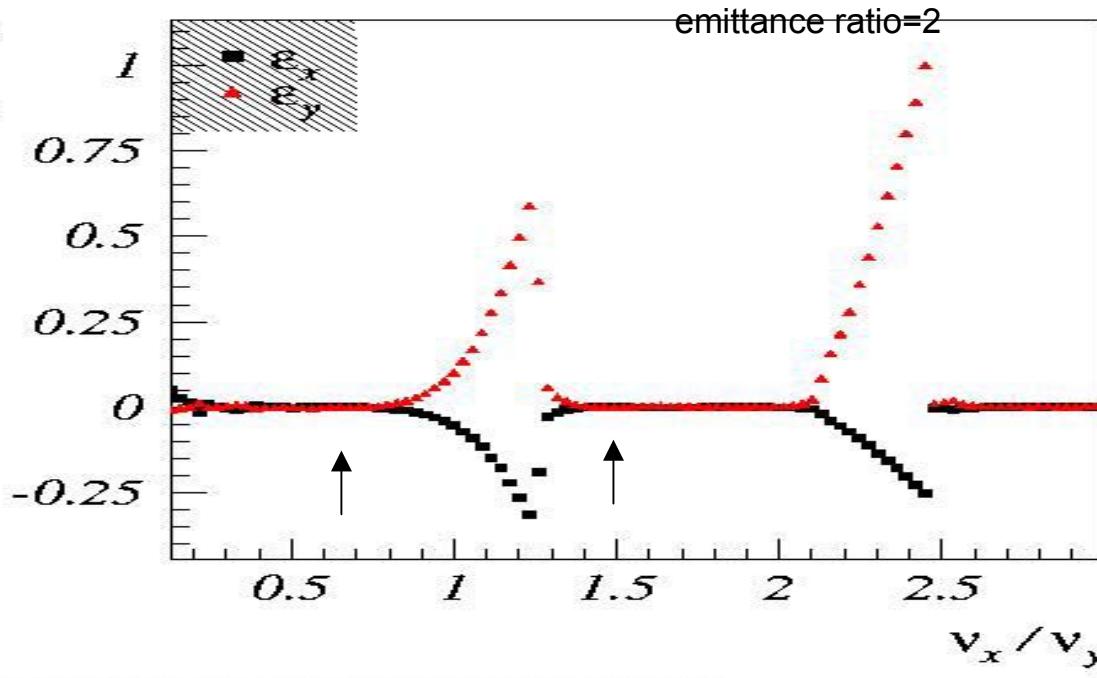
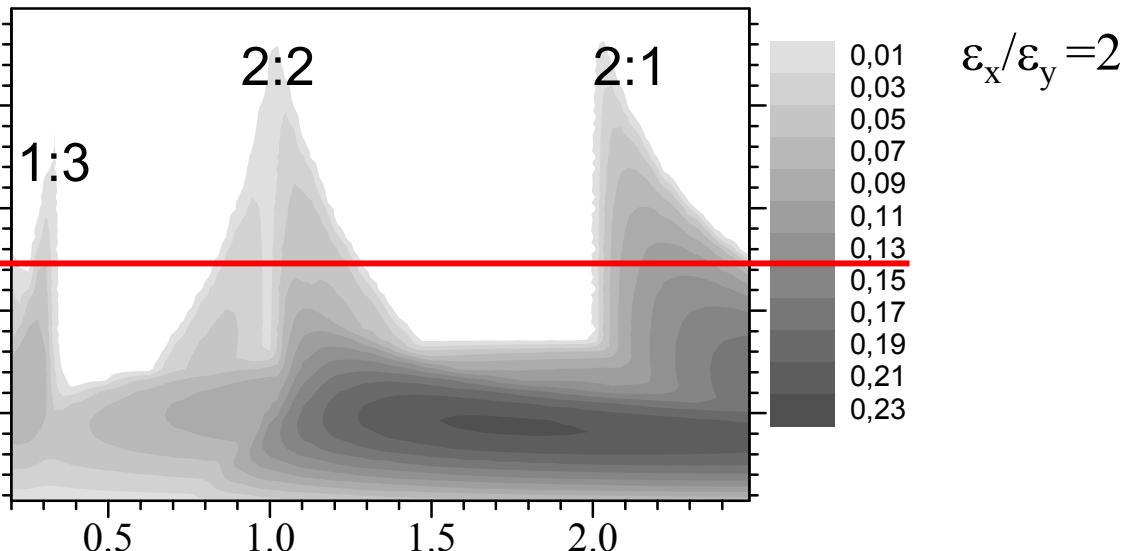
(I.H., J. Qiang, R. Ryne, PRL 86 (2001))

- initial rms-matched waterbag distribution (realistic)
- 2-10 million simulation particles on 64x64x64 grid



I.H., J. Qiang, R. Ryne, PRL 86 (2001)

Recent „scans“ in parameter space on ~40 Galaxy processors at BNL to check if „hidden“ further resonances + systematic picture (with G. Franchetti)

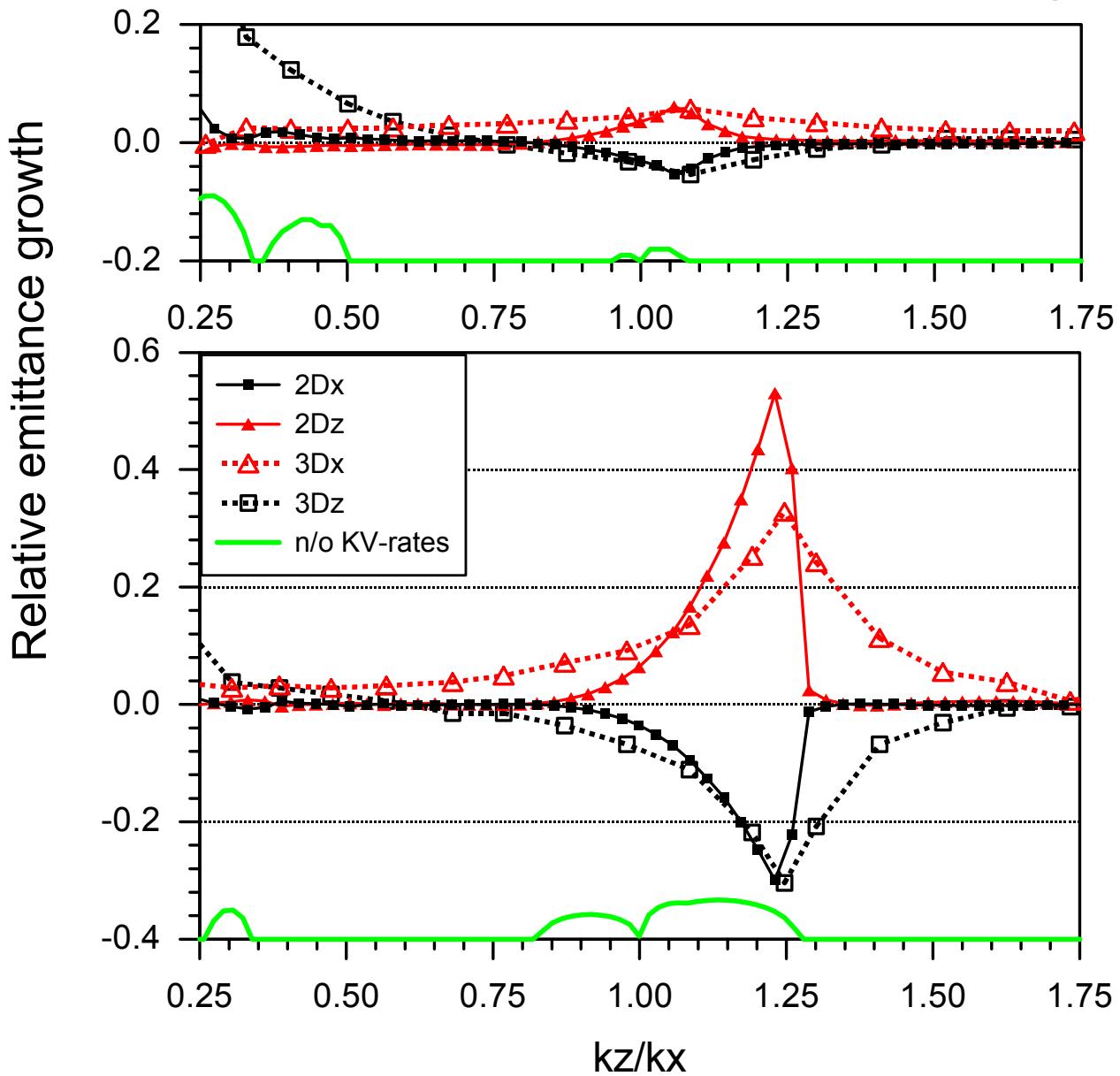


Clear evidence that no resonances higher than 4th order!

(except for KV-beam, where 5th order 3:2 and 2:3 were found)

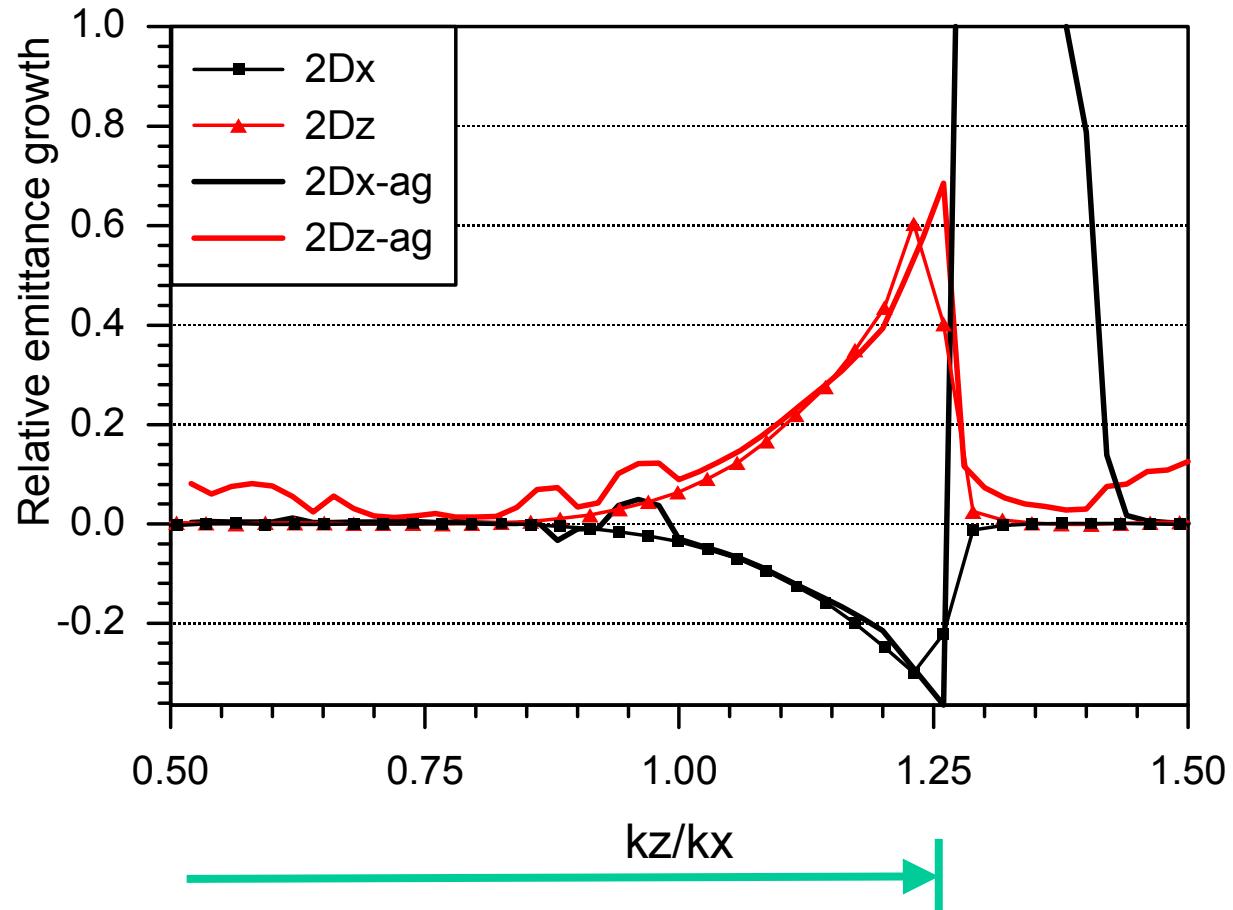
Benchmarking of 2D-code vs. theory

Compared cuts in 2D with 3D (IMPACT-code) and constant focusing



AG –focusing (FODO with $\sigma_x = 80^\circ$ kept constant)

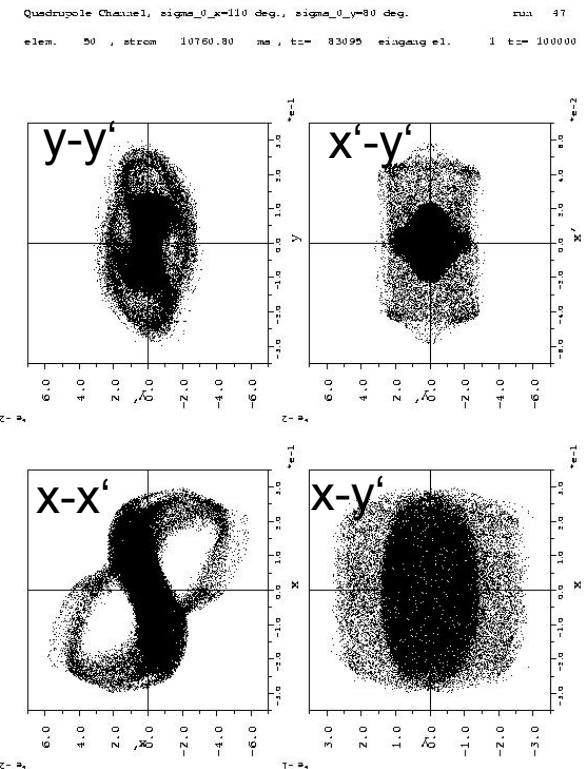
varied zero-current phase advance in z beyond 90°



good agreement AG-constant focusing
 kz/kx is relevant parameter!

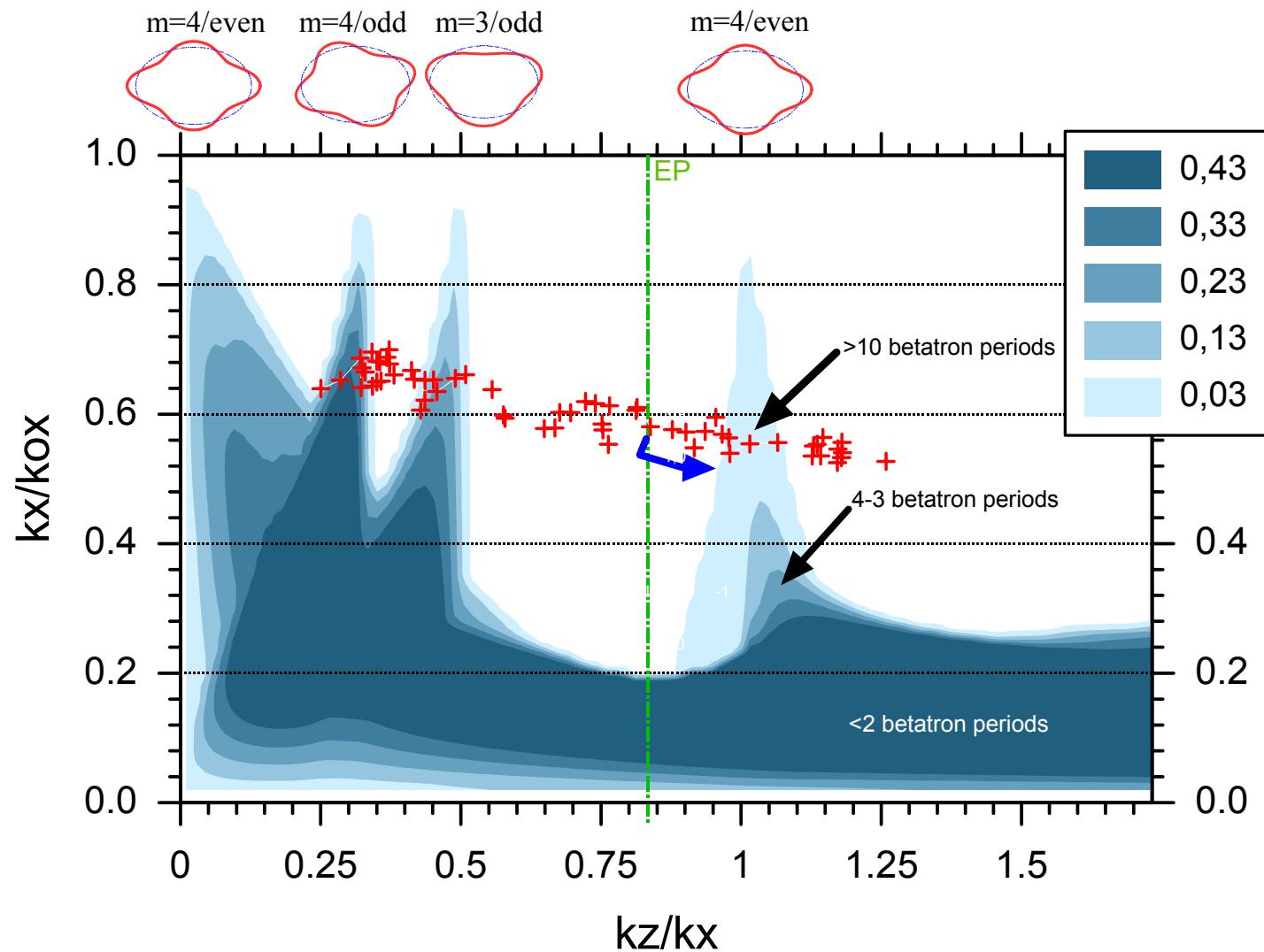


Envelope instability $\sigma_z > 90^\circ$
 Limits sc linacs!

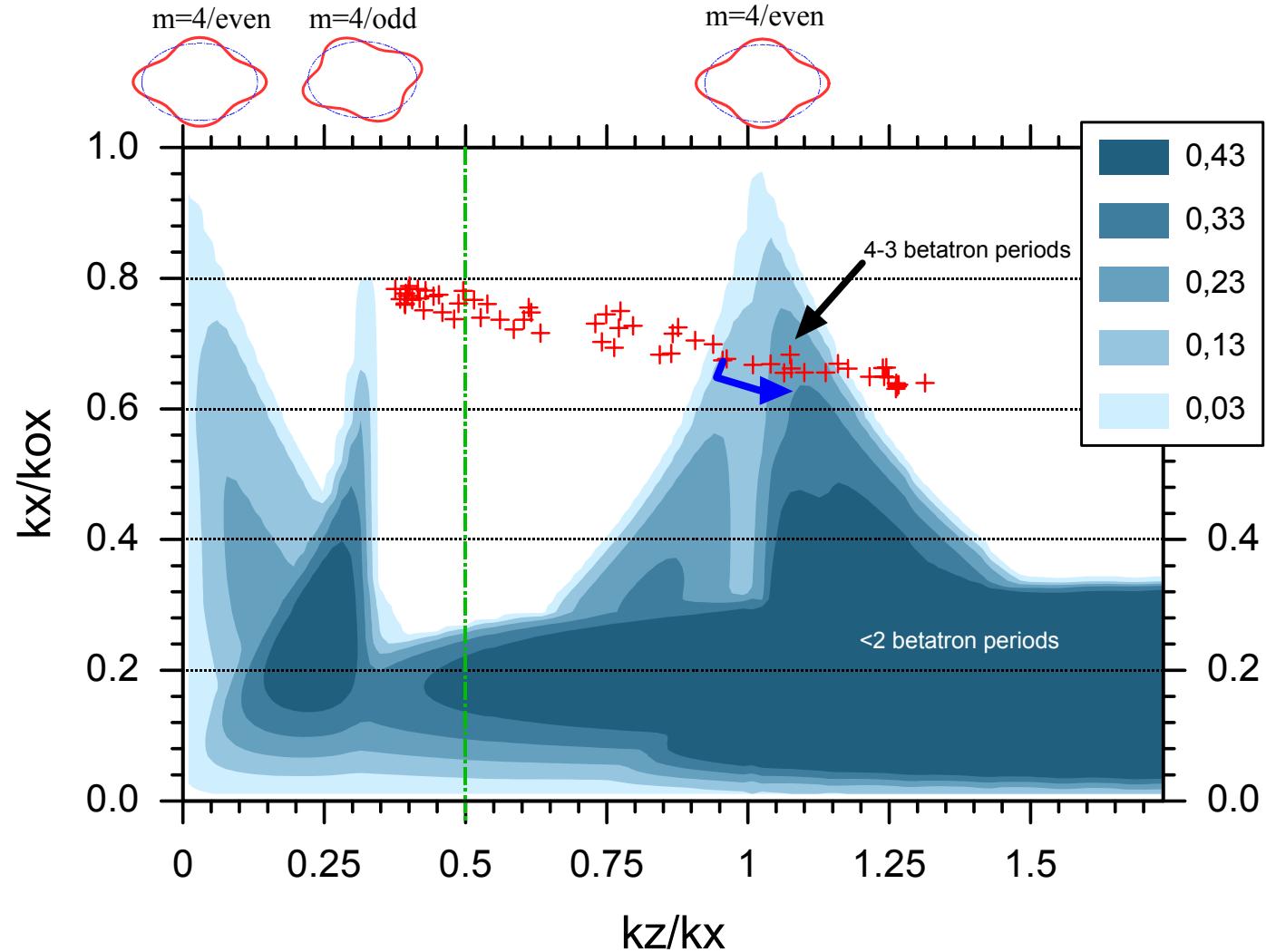


In x phase space evidence
 of structure resonance driven
 by periodic focusing

SNS nominal emittance ratio is 1.2

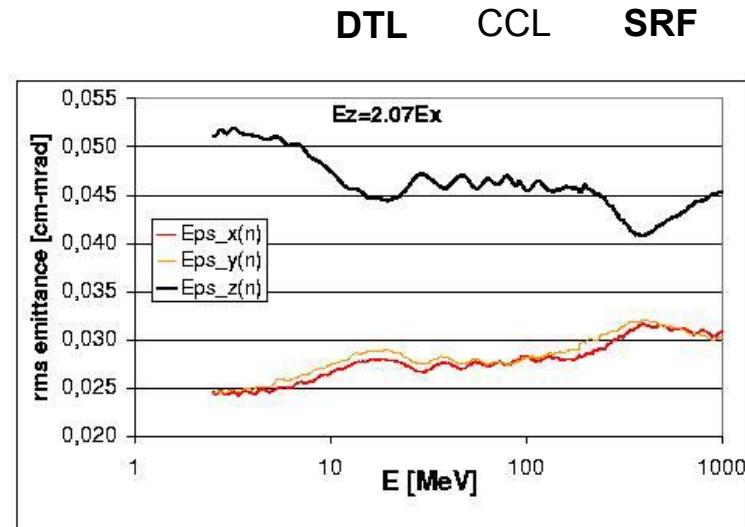


Doubled longitudinal emittance as part of error study

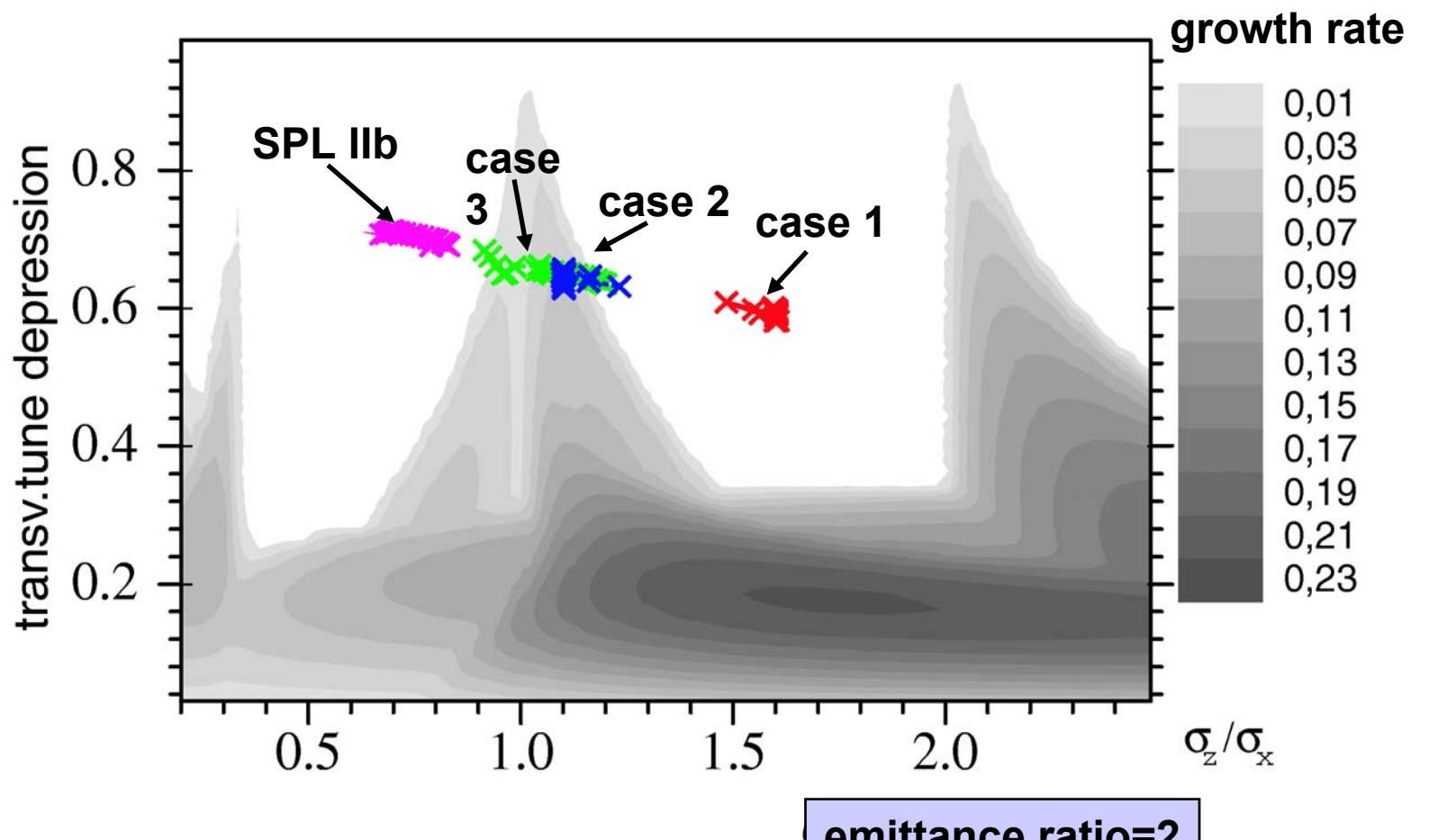


Two crossings found in Parmila simulations for SNS

Two fast crossings may lead to almost maximum exchange (30-40%)
for doubled longitudinal emittance

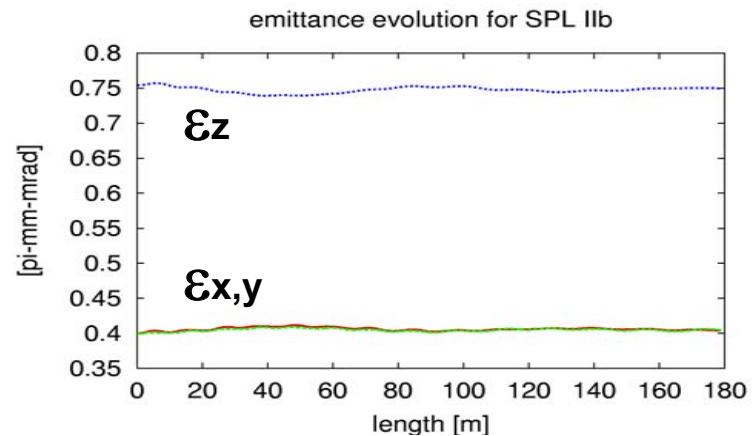
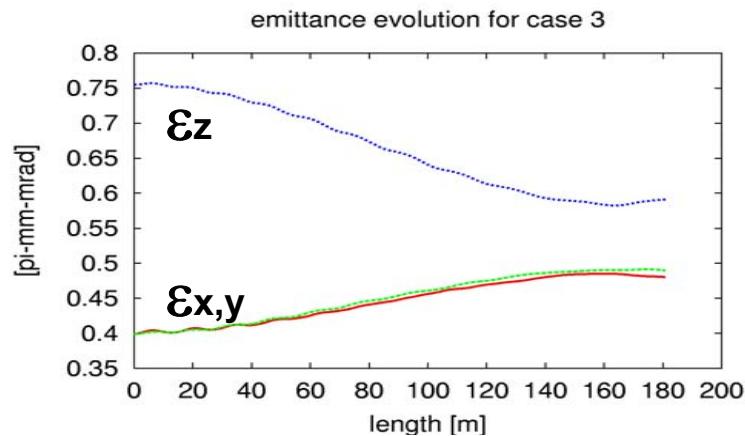
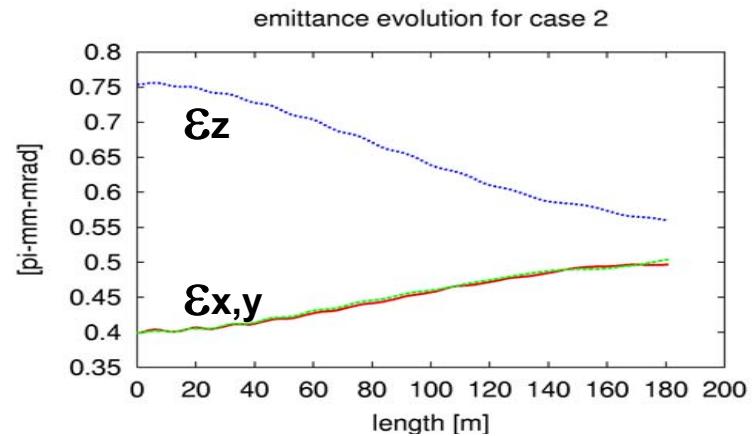
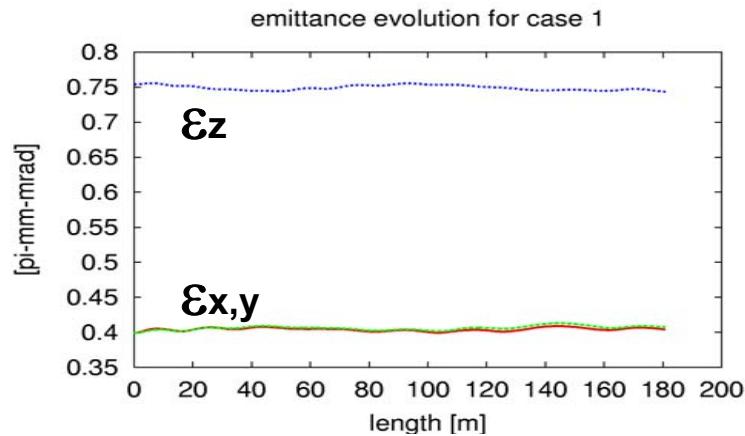


Stability Chart for the CERN-SPL study (emittance ratio of 2)



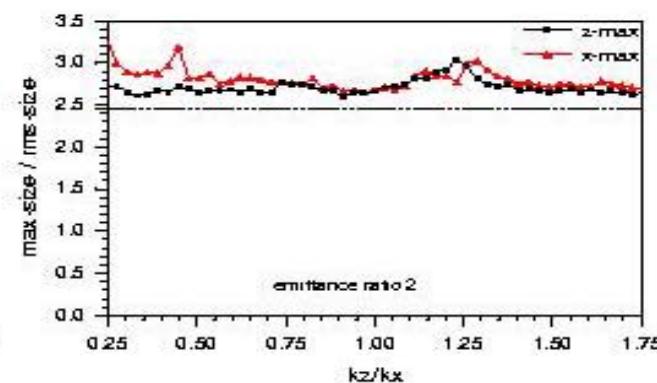
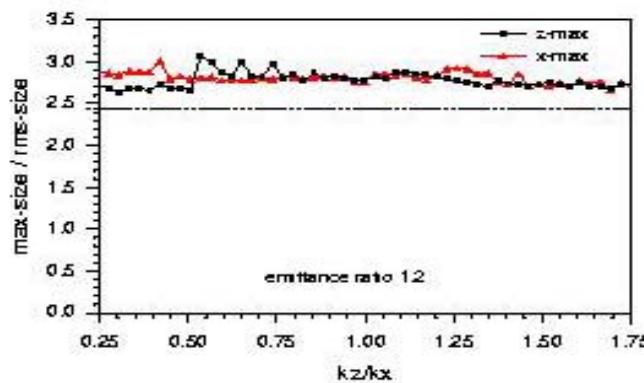
emittance ratio=2

emittance



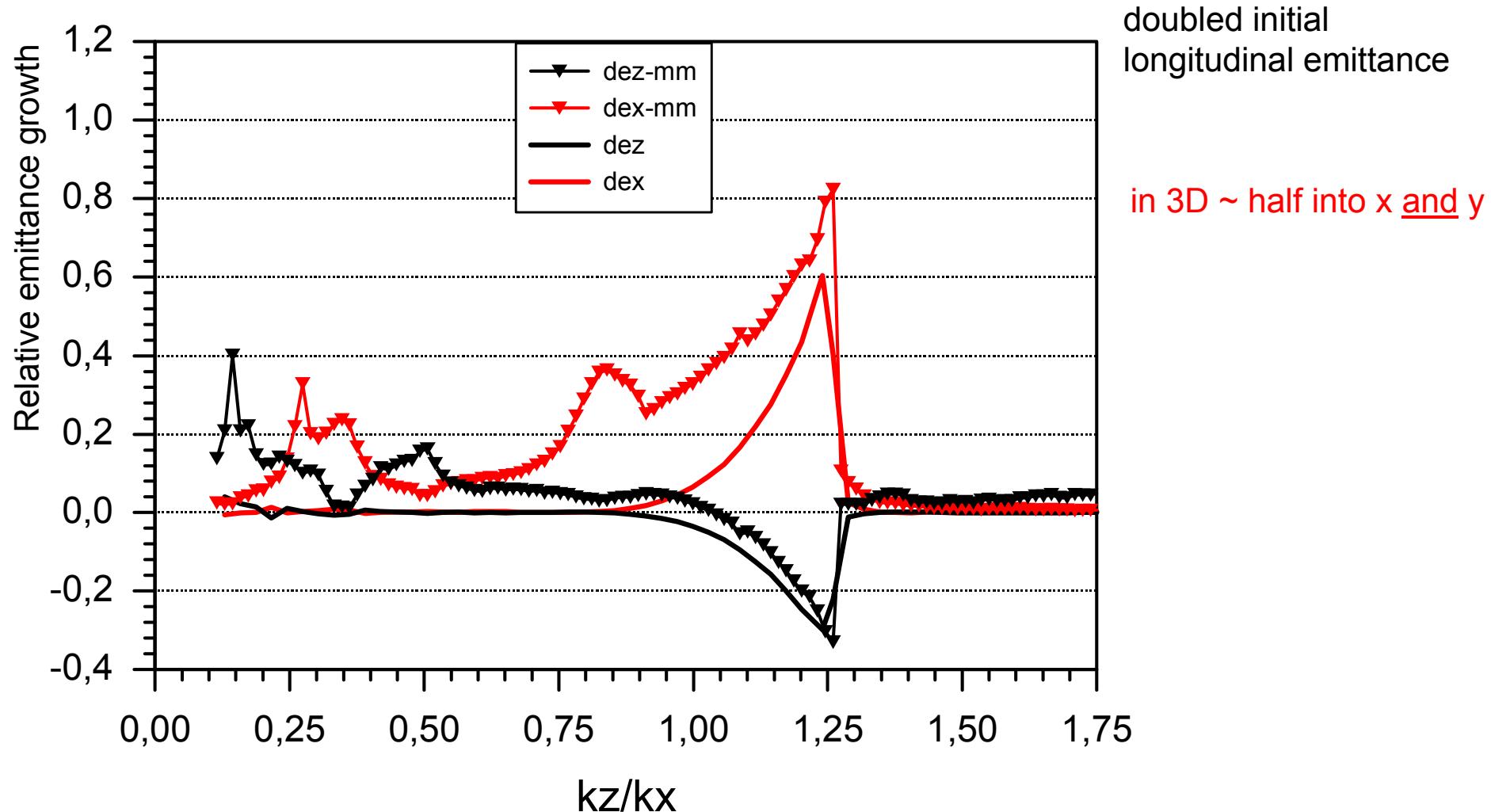
Anisotropy resonance occurs in core – ‘no’ halo

Resulting rms mismatch is negligible,
hence only 20-30% halo found



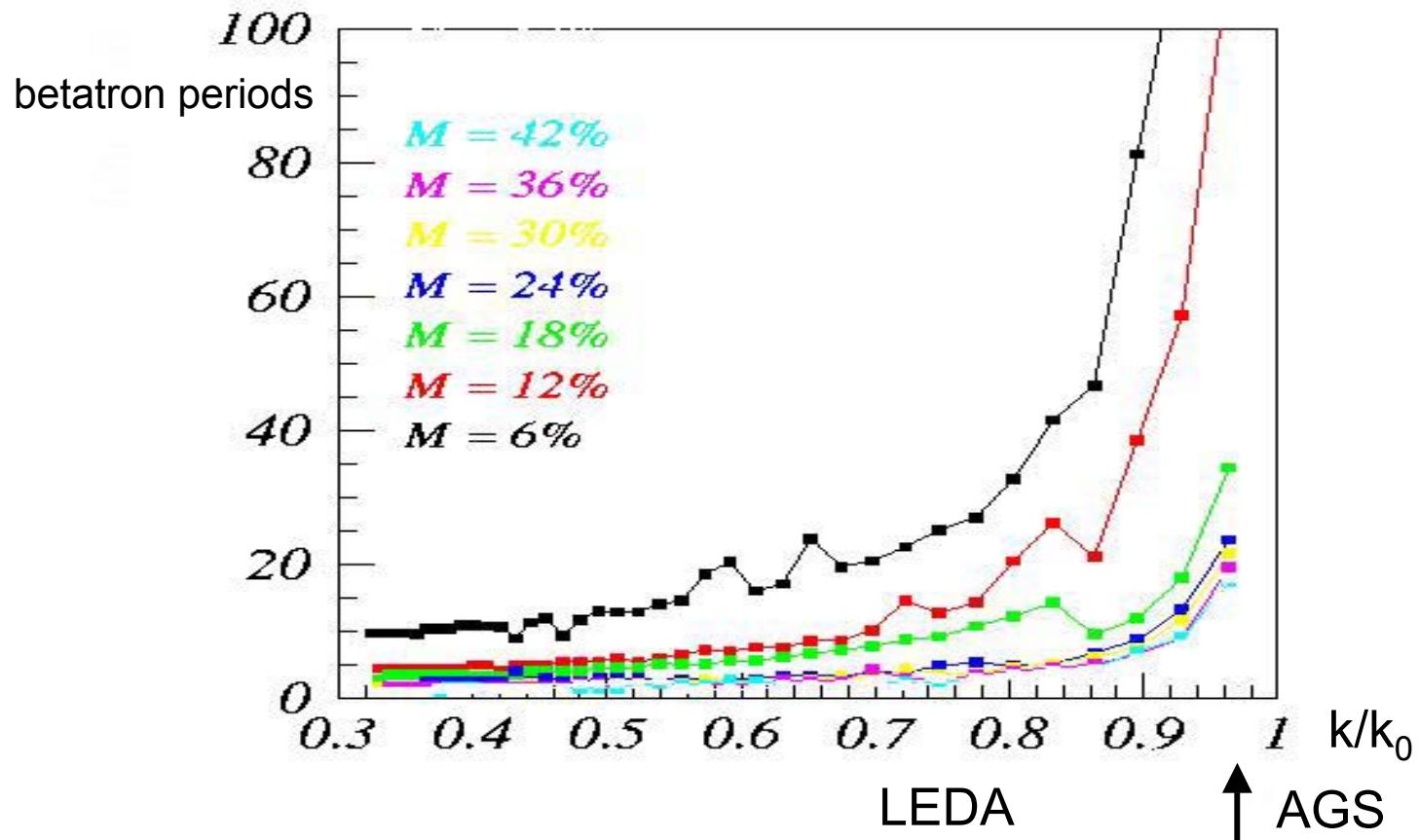
MM effect enhanced by anisotropy

example MMz=1.3 / MMx=1.0 has sizable effect in x!



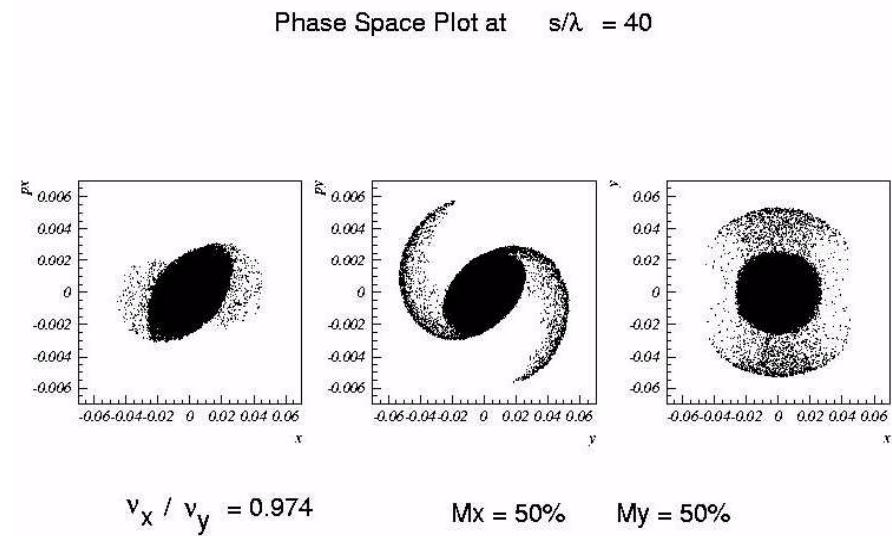
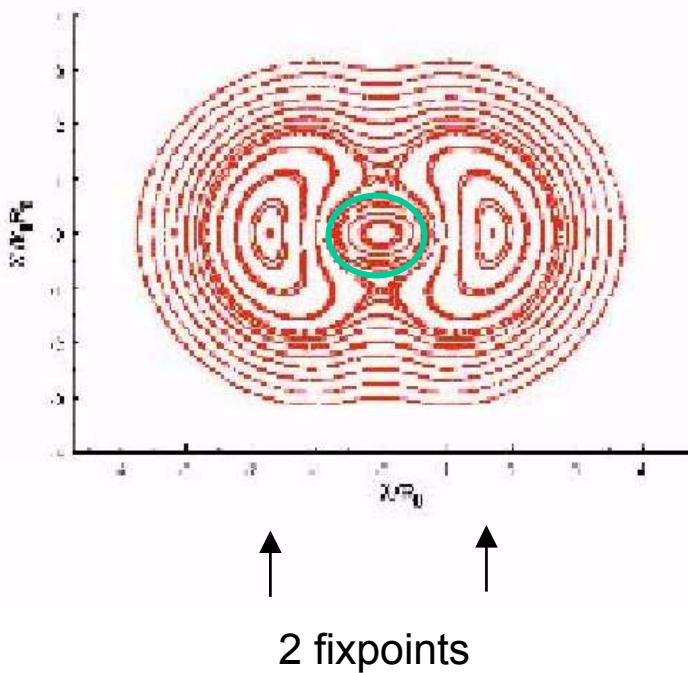
Mismatch and 2:1 resonance halo: halo build-up time (isotropic beams)

for symmetric focusing and AG-focusing



Injection mismatch and halo losses

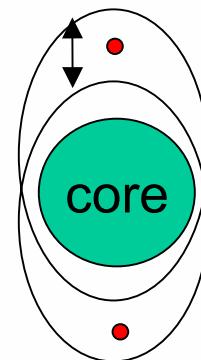
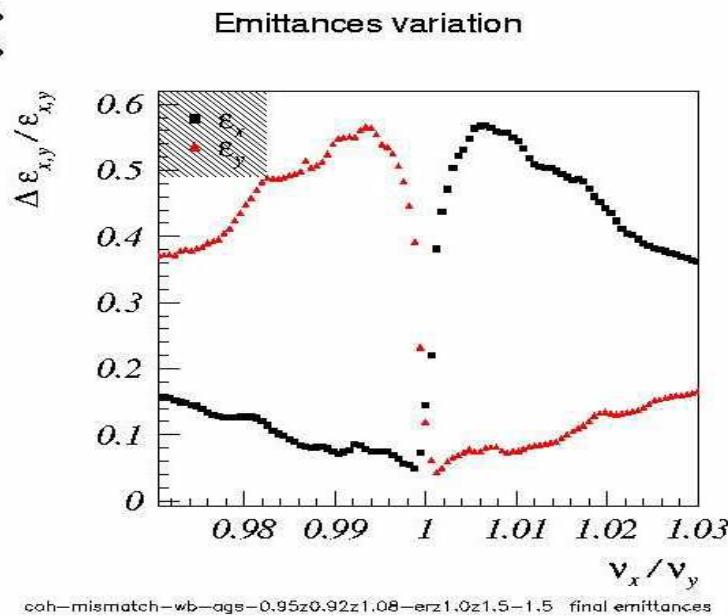
applied in an idealized model as a first step
to model injection loss into AGS at Brookhaven
- to be extended to bunches and full lattice
(G. Franchetti, I.H., A. Luccio)



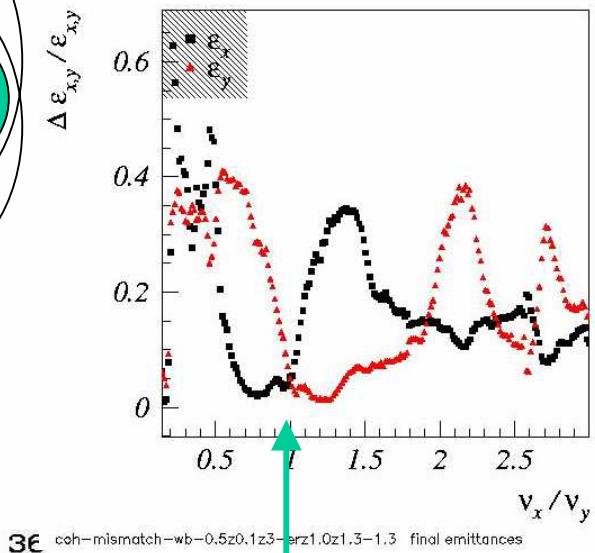
G. Franchetti

Anisotropic halo (tune split!)

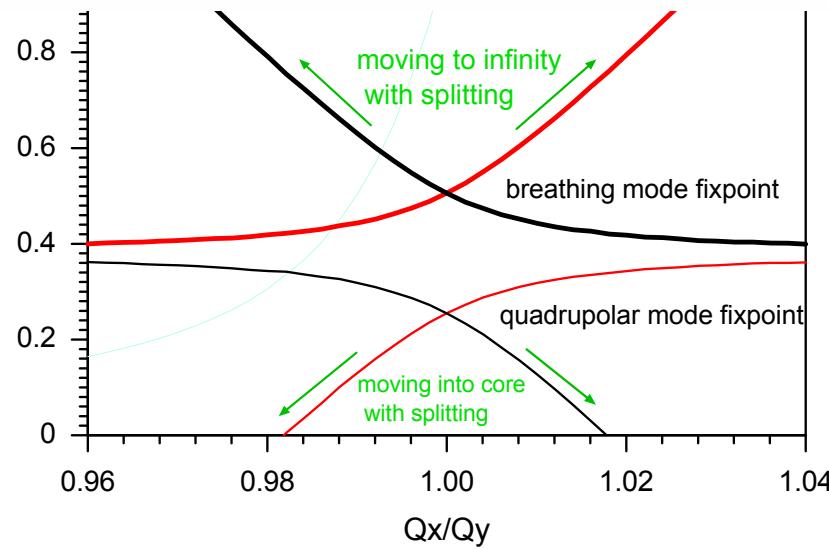
$M_x = 50\%$
 $M_y = 50\%$



$M_x=M_y=30\%$
 $k_y/k_{y0}=0.5$



symmetric breathing mode



Suggest: asymmetric focusing
for LEDA-experiment to enhance
signature of halo

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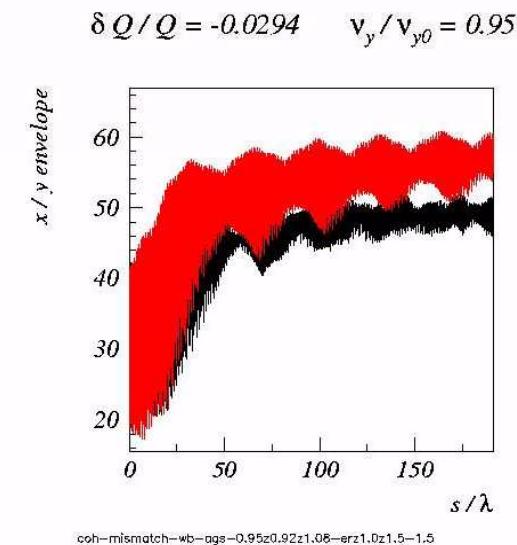
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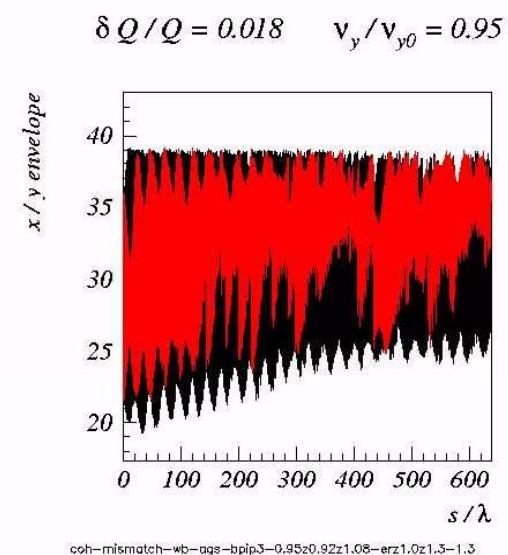
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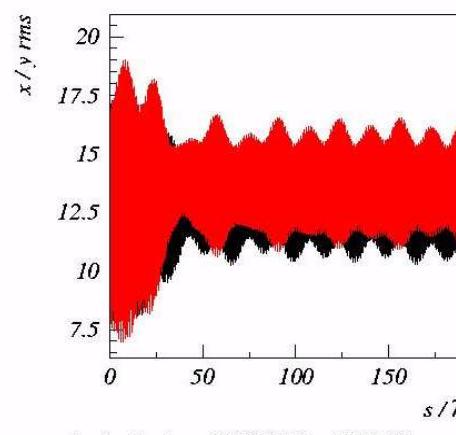
maximum size
(mm)



G.Franchetti

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$\delta Q / Q = -0.0294 \quad v_y / v_{y0} = 0.95$

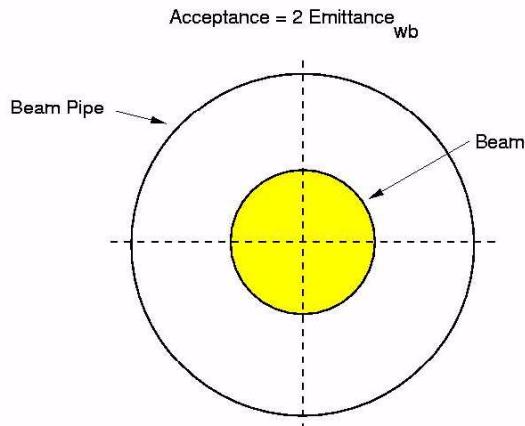


no full damping of
rms oscillations
(function of tune
split)

G.Franchetti

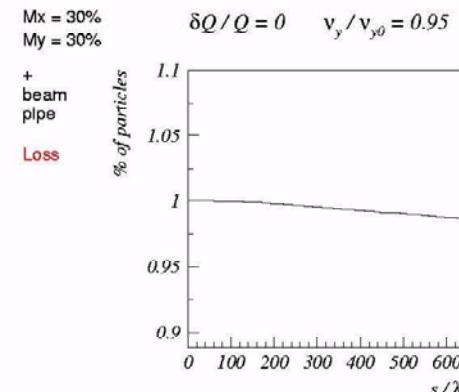
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Aperture loss modelling for AGS



G Franchetti

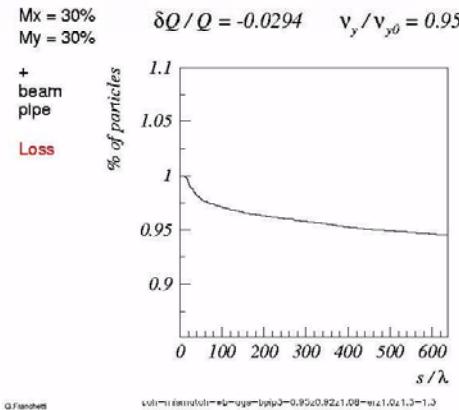
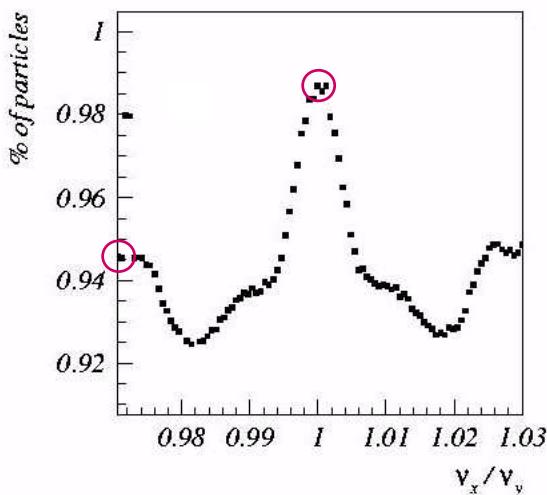
66



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EFFICIENCY

M_x = 30%
M_y = 30%



54

Conclusions

- Space charge resonance model now well confirmed by simulation in 2D and 3D – develops unchanged for periodic focusing
- Confirmed also in IMPACT (CERN) and PARMILA simulations for SNS linac: no concern for design emittances (emittance ratio ~ 1) ; 30-40% transverse emittance growth (in x and y) would arise for doubled input longitudinal emittance
- Generic 2D mismatch studies have shown that rms and halo growth is a function of the tune ratio due to „floating“ fixpoints for 2:1 resonance; worse for mix of mismatch modes or initial halo (from RFQ)
- Next: need to combine initial mismatch with error-driven mismatch and study effect of emittance growth
- Prepare experimental studies in boosters and synchrotrons